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## **LEU WWR-M fuel assemblies burnable test**

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*The tests were conducted as a part of the Russian Federation Ministry of Atomic Energy (Minatom RF) program to decrease the enrichment of the exported research reactor fuel elements, and with the support of the Argonne National Laboratory, USA.*

### **Abstract**

The results of in-pile irradiation tests of LEU WWR-M2 fuel assemblies with reduced enrichment of fuel are submitted in the report. The tests are made according to the Russian Program on Reduced Enrichment for Research and Test Reactors (RERTR). United States Department of Energy and the Ministry of Atomic Energy of Russian Federation jointly fund this Program.

The irradiation tests of 5 WWR-M2 experimental assemblies are carried out at WWR-M reactor of the Petersburg Nuclear Physics Institute (PNPI).

The information on assembly design and technique of irradiation tests is presented. In the irradiation tests the integrity of fuel assemblies is periodically measured.

The report presents the data for the integrity maintained during the burnup of 5 fuel assemblies up to 45%. These results demonstrate the high reliability of the experimental fuel assemblies within the guaranteed burnup limits specified by the manufacturer. The tests are still in progress; it is planned to test and analyze the change in integrity for burnup of up to 70% - 75% or more.

LEU WWR-M2 fuel assemblies are to be offered for export by their Novosibirsk manufacturer. Currently, HEU WWR-M2 fuel assemblies are used in Hungary, Ukraine and Vietnam. LEU WWR-M2 fuel assemblies were designed as a possible replacement for the HEU WWR-M2 fuel assemblies in those countries, but their use can be extended to other research reactors.

## **Introduction.**

The Soviet Union developed several designs for multipurpose research reactors, such as WWR-S, WWR-M, WWR-SM, and similar models. These reactors were built and are used in the nations of the former USSR as well as in several other countries. The fuel elements used are WWR-M2 (or similar models) with 36% or 90% enriched uranium (fig. 1). The fuel assemblies differ in the length (in the case of WWR-SM) and the number of cylindrical, concentric fuel elements in the assembly (in the case of WWR-K and WWR-TS), leading to a different pitch in the grid.

As a part of the Russian program to reduce fuel enrichment, the Novosibirsk factory NZHK manufactured an experimental set of fuel assemblies with less than 20% enrichment. Five such assemblies are being tested on the WWR-M reactor of the Petersburg Nuclear Physics Institute.

### **1. Characteristics of the WWR-SM reactors and fuel element testing conditions.**

WWR-SM reactors usually have a 100 liter core and operate at 10 MW or at a slightly higher power level. The typical mean heat release is 100 kW per liter of core volume. WWR-M reactor for many years used HEU WWR-M2 fuel at maximum power 18 MW and specific power 410 kW/l [1]. Nowadays WWR-M reactor use HEU WWR-M5 fuel. LEU WWR-M2 experimental fuel assemblies are tested directly in the core of the WWR-M reactor, which is loaded with WWR-M5 fuel assemblies. Table 1 shows the characteristics of the experimental LEU fuel assemblies; table 2 and figures 2 and 2a show the characteristics of the WWR-M5 fuel assemblies. One can see that the fuel assemblies generally used in the core are some different from the experimental fuel assemblies being tested: WWR-M5 fuel elements have 90% enrichment, approximately 1.5 times higher hydraulic resistance than WWR-M2 fuel elements [2], and also 1.5 times higher U-235 loading than WWR-M2. It was estimated that using fresh fuel, the experimental fuel assemblies could reach a heat release level of up to 400 kW/l [1]. The actual tests were mostly conducted at around 200 kW/l. Other testing conditions, such as the velocity and quality of water, the temperature of the cladding material, the pressure, and the variation in heat release almost match the conditions in which LEU WWR-M2 fuel assemblies will be used in the future.

## 2. Testing technique.

The tests are made using a technique developed at PNPI

The technology of the tests provides for:

- The control of integrity of fuel elements before they are loaded into the core. The coolant from the experimental loop, both in liquid and gas phases, is sampled for fission products;  $\beta$ , the quantitative parameter of non-integrity of the fuel assembly is determined from the sample analysis. Such preliminary tests allow early detection of possible defects of manufacture.
- The loading of fuel assemblies into the core, and their operation under the same conditions as serially assembled ones. During this time, the integrity of the core as a whole is monitored.
- Periodic checks for fuel assembly integrity in the experimental loop after the necessary fuel burnup is achieved. Generally, 3 to 5 measurements are taken in the experimental loop during these tests.

The experimental loop is equipped with: an independent cooling system; the instrumentation necessary for monitoring and measurement; a system for continuous monitoring of fuel integrity using delayed neutrons; and a sampling system for fission products in coolant (water) and gas (air) in order to measure the integrity parameter of the fuel assemblies.

Integrity was chosen as the criterion of fuel assembly serviceability. The quantitative parameter of non-integrity,  $\beta = V/Q$ , is defined as the ratio of  $V$ , the rate at which fission products appear in the coolant, to  $Q$ , the rate at which they are generated in the fuel [3].

The value of  $\beta$  is determined using the following gaseous radionuclides:  $^{85m}\text{Kr}$ ,  $^{87}\text{Kr}$ ,  $^{88}\text{Kr}$ ,  $^{135m}\text{Xe}$ , and  $^{138}\text{Xe}$ . The rate at which fission fragments are generated is calculated using the value of heat release, which is determined using thermal monitoring instruments in the experimental loop.

Experiments in the core are monitored with the system for continuous monitoring of core integrity using delayed neutrons, and by monitoring the value of  $\beta$  for the core as a whole.

The operational parameters of the experimental fuel assemblies in the core are calculated using HEXA, a 2D-diffusion computer program. The heat release calculations were checked by measurements done using activation monitors before the beginning of the experiments. The difference between the experimental and calculated values of heat release did not differ by more than 10%.

## 3. Results and plans for future experiments

Before being loaded into the core, all five fuel assemblies demonstrated a high degree of integrity. The fission product leakage was below the sensitivity of the technique used;  $\beta < 3 \cdot 10^{-7}$ . Measurements at around 20%, 35% and 45% burnup resulted in  $\beta$  values within  $(1-2) \cdot 10^{-6}$ .

Such fuel assembly behavior is characteristic of those normally used in the WWR-M reactor. The value of  $\beta$  rapidly rises to  $10^{-6}$  after the first few cycles that the fuel assemblies spend in the core and afterwards integrity decreases slowly, and  $\beta$  increases only gradually. Somewhere higher 50% burnup the rate of growth of  $\beta$  increases noticeably [4]. The values of  $\beta$  for different fuel assemblies differ by several times, but in the case of fuel assembly failure,  $\beta$  rises by several orders of magnitude.

The initial sharp increase in  $\beta$  can be explained by the adsorption of uranium onto fresh fuel elements. The core as a whole is characterized by  $\beta$  values on the order of  $10^{-6}$  and sometimes of up to  $10^{-5}$ . Such parameters for the core as a whole create no difficulties in terms of radiation exposure, which is well within international and nations healthy norms and thus does not hinder the operation of the reactor.

During the course of the experiment, before the fuel assemblies reached 45% burnup, the assemblies were moved to different core cells many ( $\approx 10$ ) times, and thus at different times they were surrounded by different fuel assemblies of the WWR-M reactor. The configuration of the core itself was also changed depending on other experiments that the reactor was used for. Due to such operating conditions, the range of mean heat release of the experimental fuel assemblies was from 18 to 326 kW/l and the range of the calculated fuel element surface temperature was from 48 to 95°C. The detailed data are presented in table 3.

The measurements taken on the experimental fuel assemblies as well as the behavior of  $\beta$  measured for the core as a whole when all five assemblies were loaded strongly suggest that the experimental fuel assemblies retained integrity within the maximum burnup limit specified in the manufacturer's warranty.

The comparison of LEU WWR-M2 and usual loaded in WWR-M reactor HEU WWR-M5 on parameter  $\beta$  is given in Fig. 3.

The tests are still in progress and we plan to reach 70-75% burnup, depending on the behavior of  $\beta$ . 75% burnup corresponds to  $10^{21}$  fissions per cubic centimeter of fuel, which is less than the highest fission density achieved in research reactor fuel elements such as HFR – Netherlands, HFR – ILL and HFIR- USA [5].

Special conditions in the reactor core must be created to reach such high burnup because the concentration of uranium in the experimental fuel assemblies will fall to approximately 30% of the mean concentration in the core. In order to speed up burnup, the experimental assemblies must be placed in the regions of highest neutron flux, or more specifically, such regions must be created in the core. Fig. 4 shows one core loading configuration which has such regions. Of course, such loading configurations would lead to some increase in fresh fuel consumption.

## 4. Conclusions

The measurements taken on the experimental fuel assemblies WWR-M2 with uranium 235 enriched to 19.75% and with fuel density  $2.5\text{g/cm}^3$  strongly suggest that the experimental fuel assemblies retained integrity within the maximum burnup limit specified in the manufacturer's warranty for utilization in reactors of WWR-M type. The tests are still in progress and we plan to reach 70-75% burnup.

More promising is the development of LEU WWR-M5 on the basis of high-density fuel. WWR-M5 fuel elements give the attainability to increase the maximum specific heat release in the core from 400kW/l up to 900kW/l without modification in the cooling loop.

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### **References.**

1. A.A. Enin, A.N. Erykalov, G. A . Kirsanov, K.A. Konoplev, V.S. L'vov, Yu. V. Petrov, Yu. P. Saikov, A.S. Zakharov, V.S. Zvezdkin Design and experience of HEU and LEU fuel for WWR-M reactors. Nuclear Engineering and Design. 1998, 182, 233
2. G. A . Kirsanov, K.A. Konoplev, R.G. Pikulik, J. A. Shyshkina. WWR-M core hydraulic. Atomnaya Energia 1975, 39, (5), 322 and A.N. Erykalov, V.S. Zvezdkin, G. A. Kirsanov, K.A. Konoplev, V.S. L'vov, Yu. V. Petrov and A. P. Ruzmanov. Fuel Elements with thin walls for Research Reactors. Atomnaya Energia 1986, 60, (2), 105
3. G. A .Kirsanov, K.A. Konoplev, Yu. P. Saikov, A.S. Zakharov. The Test method and some results for WWR-M fuel., The 21<sup>st</sup> International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR) October18-23,1998, San Paulo, Brazil.
4. K.A. Konoplev, R.G. Pikulik, Yu. P. Saikov,1988. The check-up of assembly hermetically on the WWR-M reactor of LNPI AN USSR. Methodical and Applied Investigation of LNPI. Leningrad, pp. 129-130.
5. Directory of Nuclear Reactors. IAEA, Vienna, 1998

**Tab 1****The main characteristics of LEU WWR-M2 fuel assemblies.**

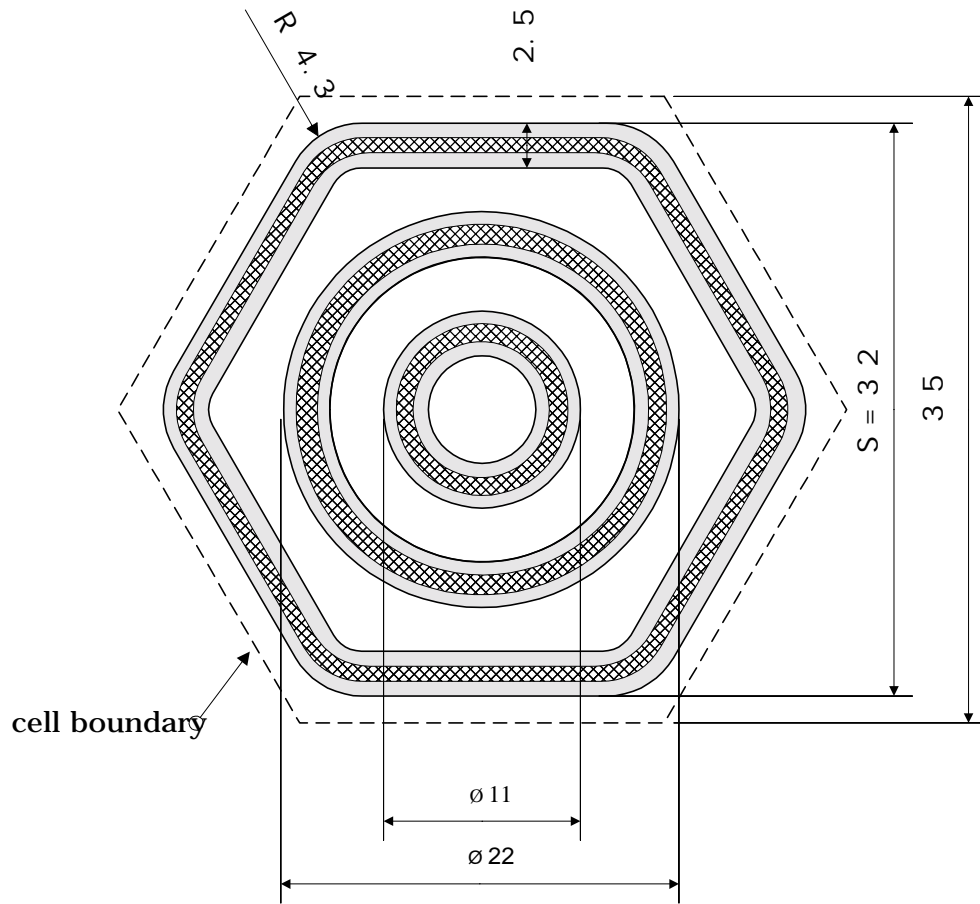
<sup>235</sup> U enrichment -	19,75 %
Average weight of uranium in assembly -	40,9 g
(design weight for 500 mm active length) -	41,7 g
(design weight for 600 mm active length) -	49,7 g
Fuel element tubular type with thickness -	2,5 mm
Uranium density of fuel meat -	2,5 g/cm <sup>3</sup>
Fuel meat -	UO <sub>2</sub> +Al
Cladding -	aluminum alloy (SAV1)
Cladding thickness	0,72 mm

**Tab 2****The main characteristics of HEU WWR-M5 fuel assemblies.**

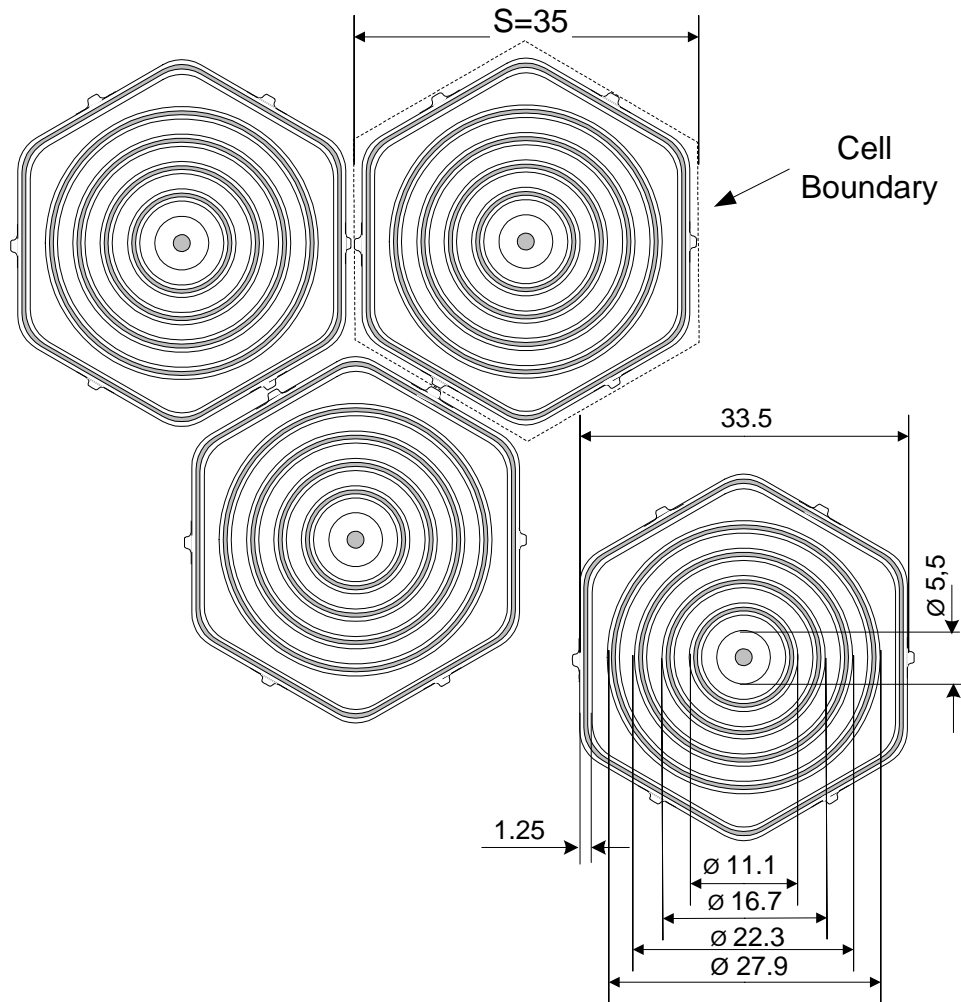
Fuel element type -	tubular type
<sup>235</sup> U mass in FA -	66g
<sup>235</sup> U Enrichment -	90%
Composition of meat -	UO <sub>2</sub> +Al
U meat density -	1,087 g/cm <sup>3</sup>
Fuel element thickness (total) -	1,25 mm
Cladding -	aluminum alloy (SAV1)
Cladding thickness	0,36 mm

**Tab 3****Testing data**

FA	Mean specific power	Max specific power	Operating power time	Number of reloading	Mean burnup	non-integrity β
No	KW/l	KW/l	Days		%	
01IM43.95	179	274	194	11	46	8,5·10 <sup>-7</sup>
01IM44.95	177	285	232	9	48	1,6·10 <sup>-6</sup>
01IM45.95	177	268	228	13	46	1,7·10 <sup>-6</sup>
01IM46.95	191	262	228	11	44	1,7·10 <sup>-6</sup>
01IM47.95	192	326	234	13	48	1,5·10 <sup>-6</sup>

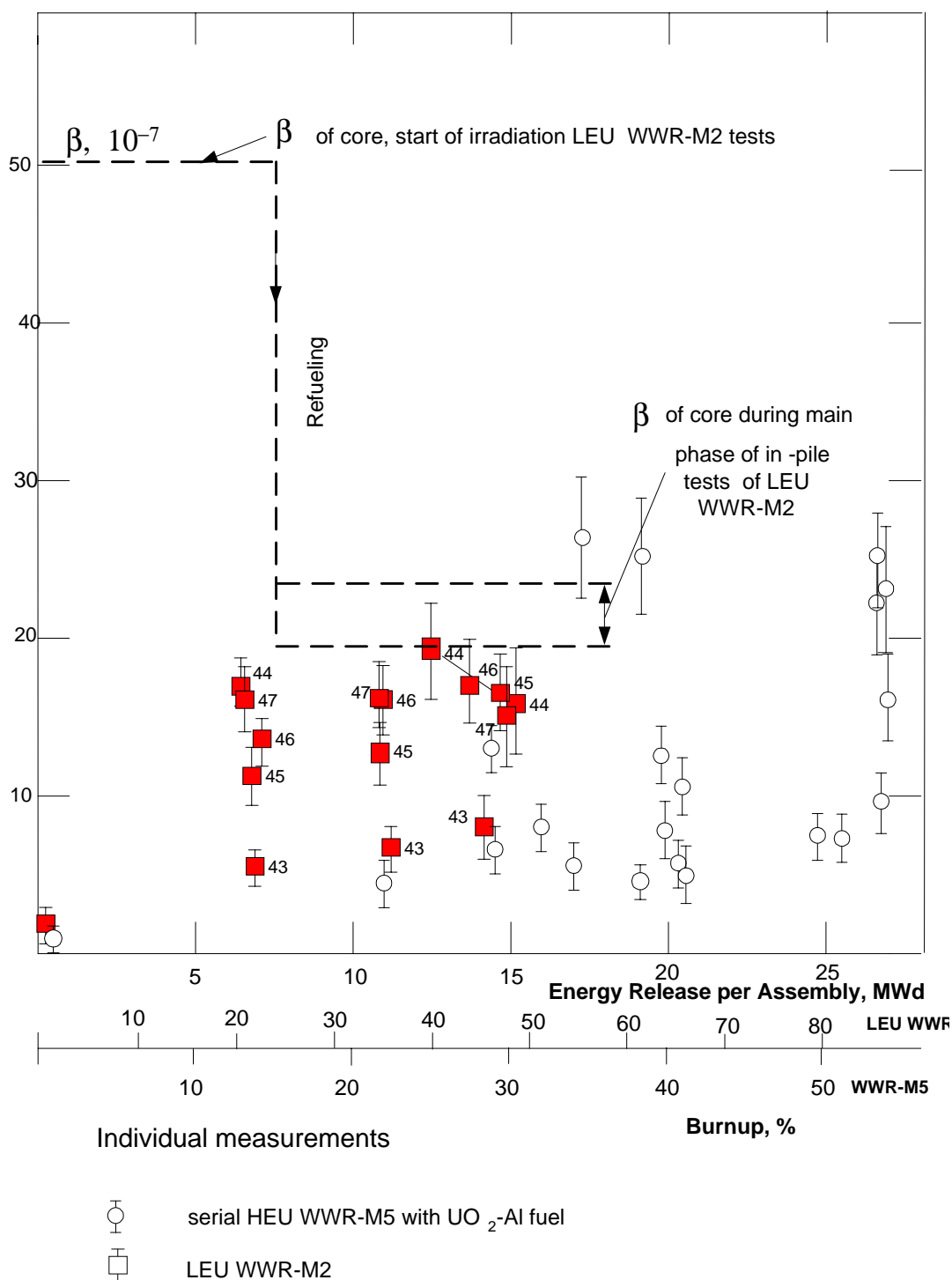


**Fig.1 WWR-M2 FUEL ASSEMBLY**

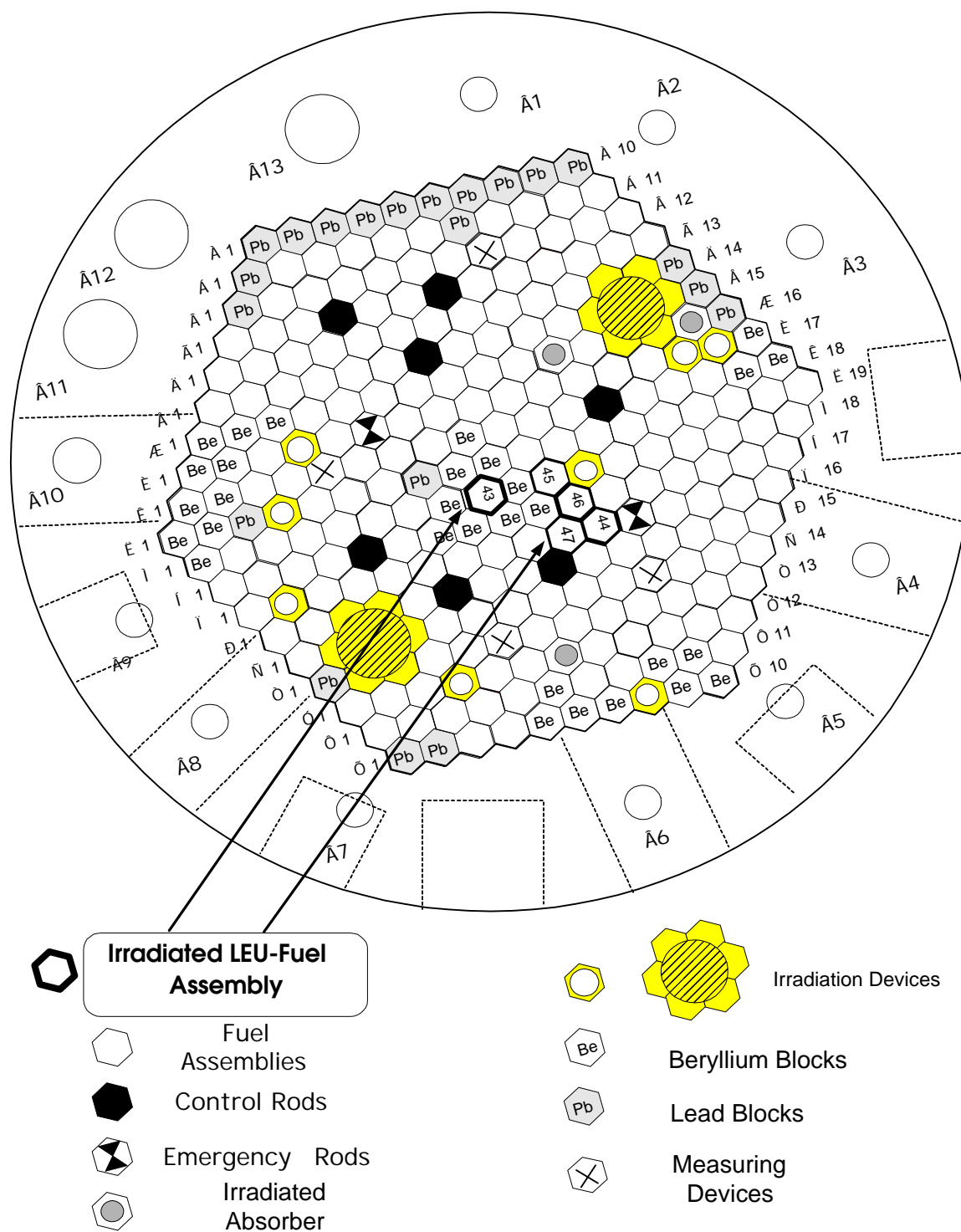


**Fig. 2 . WWR-M5 FUEL ASSEMBLY**





**Fig. 3  $\beta$  Vs. Energy Release for Different Types of Fuel.**  
*Comparison Data of Serial HEU Fuel with  
 Data of Experimental LEU WWR-M2*



**Fig. 4. Planned Position of LEU WWR-M2 FA # 43 for Power Increasing**